



Impact of 1.5 K global warming on urban air pollution and heat island with outlook on human health effects

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Projected regional climate change modifies the circulation and the radiation effects, which influence urban air pollution (UAP) and urban heat island (UHI) properties. Besides the primary effects of climate change on these urban stressors, the human health effects are also reviewed. The change is derived from the average 4.5 W m^{-2} radiation increment version of the Representative Concentration Pathways (RCP4.5) scenario for 2046–2065, which was characterized by 1.4 K global warming and maps for temperature, precipitation, air pressure and cloudiness changes maps. Regions with more anticyclonic and cloudless weather and increased temperature would definitely suffer from stronger UAP and UHI even if 1.5 K becomes the peak warming. Since, the other regional changes are fairly linear in function of the global warming (except precipitation), the smaller the warming, the more tolerable the targeted urban climate stresses are.

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Introduction

The projected 1.5 K or higher global temperature increase modify the atmospheric circulation ([1] and further sources in the next section), that is, the regional and local weather conditions of urban air pollution (UAP) and urban heat island (UHI), affecting the average and peak values, as well. UAP is defined as the different chemical composition of the air between

the cities and the outskirts, whereas UHI is defined as the difference between the observed air temperature observed in the city and in the suburban areas. Both differences may change with the global warming due to modifications of their formation conditions in the actual weather and in their statistical ensemble, called climate.

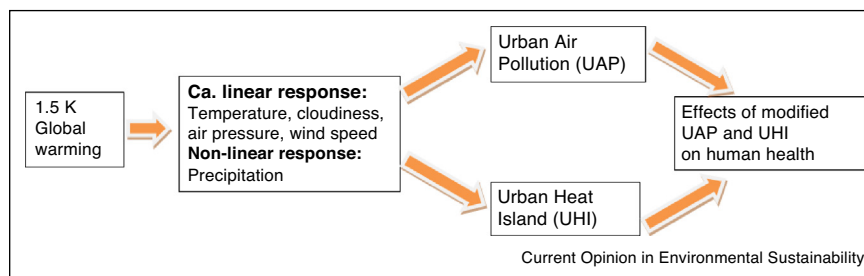
Before providing detailed surveys, some aspects of the weather influence on UAP and UHI should be pointed out. Dry and wet deposition of urban air pollution and as well, as emission of the pollutants by transport, and the possible chemical transformations directly depend on the actual weather conditions. The UHI intensity is the strongest in clear, calm anticyclonic situations, when the optical, hydrological and heat capacity differences between urban and rural circumstances are the strongest, and less disturbed by horizontal mixing. Detailed descriptions of UHI has been provided by Chapter 10.4 [2]. For air pollution including UAP, see Chapters 1–2 in [3].

This study does not provide a full survey of all impacts of climate change in the cities, but just those modifications of UAP and UHI which are related to the circulation changes. Recent scenarios related to 1.5 K and 2.0 K global warming have been pointed out [4,5].

The study is structured as follows: ‘Expected changes of climate and circulation over the world’ section summarizes the expected circulation and weather changes over the world. Sections ‘effects of climate change on urban air pollution’ and ‘effects of climate change on urban heat island’ focus on the effects above climate changes on UAP and UHI, respectively. Section ‘Effects of UAP and UHI on human health’ introduces the reader into recent results of UAP and UHI on human health. Finally, ‘Conclusion’ section points out the differences between +1.5 K and larger global changes concerning UAP, UHI and their health effects. These effects obviously depend on various social and lodging conditions of the population; however, these aspects of vulnerability are not specifically tackled by our review. Among the omitted health consequences there may also be advantageous effects of the global warming.

The content and the structure of the study are presented in [Figure 1](#).

Figure 1



Graphical abstract of the study (original image).

Expected changes of climate and circulation over the world

This review article considers the 1.5 K global warming in comparison with larger changes. Though the impacts of the global warming depend on the path as the 1.5 K target is reached (i.e. monotonic slow warming or overshooting with later return, etc.), among the global and regional climate forecast maps we generally find differences with two time averages.

The present section is mostly based on conclusions by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) [1], because the Coordinated Regional Climate Downscaling Experiment (CORDEX) [7] simulations by regional climate models (RCM) do not specifically focus on the SR1.5 (IPCC Special Report Global Warming of 1.5 K [8]) challenge, and the Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) Project [9], issued to simulate the 1.5 K global warming and compare its features to larger changes, has not yet published enough regional simulations to consider. Besides [1], findings on changes of the atmospheric circulation, reflected by [2] are also reviewed below.

Recent specification of the sixth stage of the Coupled Model Intercomparison Project (CMIP6) has been published [10], the previous stage of which (CMIP5) served as the key scientific source of global model results of IPCC AR5 [1]. The first partial publication of the results is expected to be published in 2018 [8].

Specification of the three 10 years time periods of the HAPPI Project, concerning, first, the current reference, second, the 1.5 K and third, 2.0 K warming periods is seen in [9], first publication of these investigations in the corresponding special issue [11] is still under review. These periods are different from those we apply below, but those are also time slices as in our approach.

The difference in regional averages considering 1.5 K or 2.0 K global warming may not be too large. However there are recent studies pointing at the differences between the

extreme event frequency and severity are much larger than the proportion between 1.5 K and 2.0 K. This has already been established, among others, for diurnal precipitation and temperature maxima by [12] and for drought by [13].

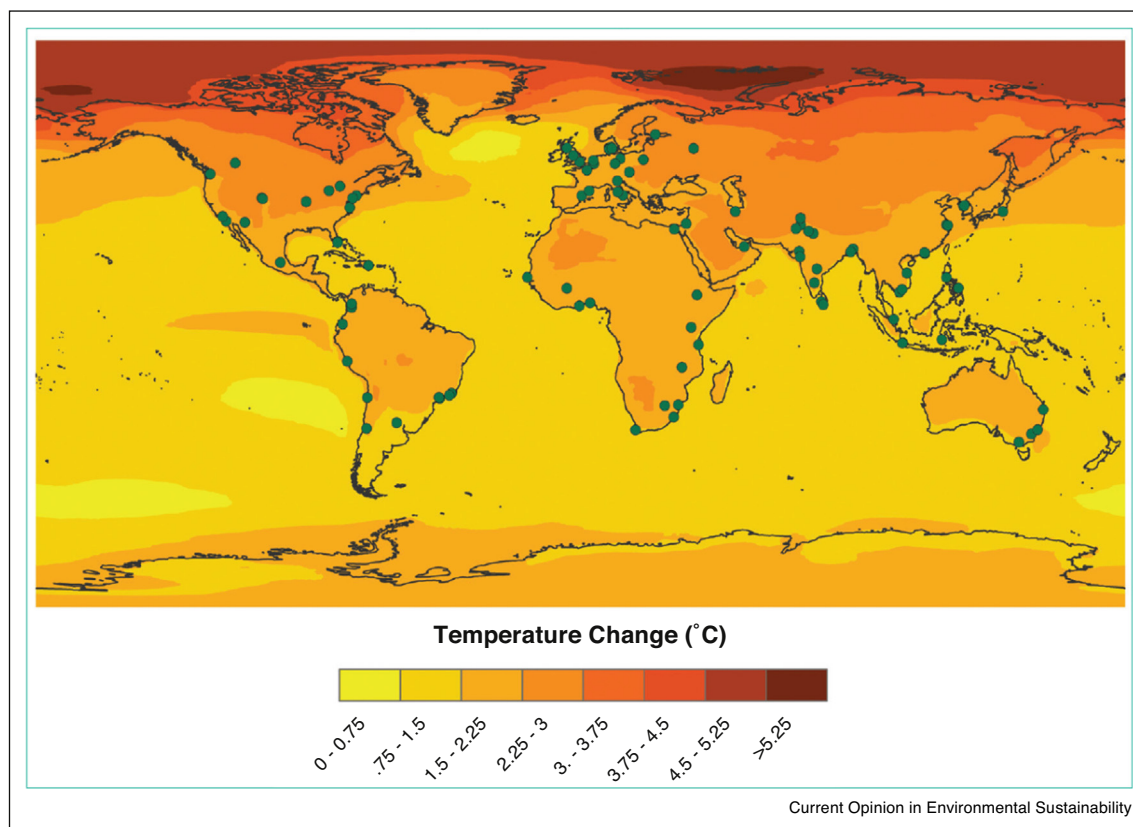
The modifications of the atmospheric general circulation are mostly based on coupled ocean-atmosphere general circulation models (OAGCM). Selecting among the Representative Concentration Pathways, one could point at the RCP4.5, which means that the radiation balance of the Earth would increase to 4.5 W m^{-2} by 2100. The actual value of this forcing is 2.3 W m^{-2} since ca. 1750. The RCP4.5 leads to 1.4 K increase in the global mean temperature for 2046–2065, whereas 1.8 K is expected for 2081–2100, both compared to 1986–2005.

One might think that the 1.4 K warming by 2046–2065 compared to 1986–2005 is not a good analogy of the 1.5 K global warming, calculated from the pre-industrial era, since between this date (ca. 1850) and 1986–2005 another 0.6 K global warming has occurred. So, the warming between ca. 1850 and 2046–2065 would really be 2.0 K instead of 1.5 K.

But, the regional features of the global warming correspond only to the 1.4 K climate shift, simulated by the models [1]. In this respect, the only assumption is that the regional climatic features of the global warming are the same for the 1.4 K global warming between 1986–2005 and 2046–2065, as they are between the pre-industrial climate and the one characterized by 1.4 K warmer climate.

To discuss this assumption, one may establish that there are recent studies reflecting non-linearity of particular responses. But they either correspond to non-linearity of impact between 1.5 K versus 2.0 K warming [4,14], or they concern particular regional non-linearities, such as impact of warming on the rainfall in the Sahel [15], or the effect of soil moisture on diurnal maximum temperature [16]. None of them is related to the assumption of similarity between two 1.5 K warming events.

Figure 2



Projected annual mean temperature change in average of 35 global climate models in 2040–2069, compared to 1971–2000 according to the RCP4.5 scenario. The global mean difference between the two periods is ca. 1.5 K in average of the elaborated CMIP5 models. The dots indicate the 100 cities characterized by [17**] (Figure 2 of [17**]).

Locations of the 100 largest cities have been studied [17**] in the field of annual mean temperature changes, as presented in Figure 2. It can be established that although the most populated cities lay out the strongest changes at high latitudes, the change can be considerably higher than the ca. 1.5 K of global warming in many cities.

Sign of precipitation changes varies from region to region in both half-years [1]. The regional precipitation modifications may be as high as several tens of a percent in either direction, even in this modest 1.4 K global warming.

Changes in the sea-level pressure patterns vary in place and in time (seasons), as well [1]. This means shifts in proportion between bright, windless anticyclones (high pressure areas), which strengthen the UHI and reduce the vertical mixing of UAP.

Recent research [18] makes it unequivocal that tropical areas have expanded poleward by 70–120 miles in both hemispheres during 1979–2009, also shifting the subtropical dry zones, mid-latitude jets and storm tracks towards

the poles. The mid-latitude circulation patterns are also perturbed in the Arctic areas, observed in the recent past and simulated for the future [19]. In connection with these changes, frequency of the persistent blocking anticyclones is likely changing [20].

The shifts of annual mean cloudiness remain within $\pm 10\%$ range even in case of the above mentioned 1.8 K scenario [1]. The observed and simulated cloud change patterns between the 1980s and 2000s are consistent with the poleward retreat of mid-latitude storm tracks, expansion of the sub-tropical dry areas [21].

Effects of climate change on urban air pollution

The climate change has several important air-chemistry concerns. One important contribution to the high rate of the present climate change is human urban activity [17**]. The air pollution mostly affects the urban areas; furthermore pollutants are transferred and distributed through long-range meteorological transport processes. The projected 1.5 K overall average global temperature increase in the near future can have considerable influence on the

chemical properties, air concentrations and lifetime of pollution components [22,23]. Urban areas also have considerable contribution to air pollution through photochemical smog in form of nitrogen oxides and volatile organic compounds.

The occurrences of ozone forming photochemical reactions involving nitrogen oxides (NO_2 , NO) in the troposphere is projected to increase with the contribution of several different emission components, carbon (CO , CO_2) and sulfur (SO_2 , SO_3) oxides. The size and quantity of particulate matter (PM) influence microclimatic conditions (formation of heat islands), moreover affect global temperature. The atmospheric positions of PM particles are affected by the size ($\text{PM}_{2.5}$, PM_5 , PM_{10}) and weather conditions. The reduced emission of particulate matter has been proposed [24] and it was expected, that the reduced black carbon emission in Europe can contribute to the decreased speed of global warming and the 1.5 K temperature increase can be sustained.

Significant harmful effect is associated with tropospheric ozone (O_3), which is a strong oxidant agent and key substance of photochemical reactions through the formation of hydroxyl radicals. Anthropogenic activity is responsible for the majority of ozone formation and decomposition. In urban areas, the trends in tropospheric ozone concentration influenced by different source and sink processes [25,26]. The elevated temperature in heat islands in urban zones favor the ozone formation especially in summer months at moderate continental climate, similar tendency can be observed in drought stricken tropical areas. Since the ozone formation is temperature dependent, projections focused on temperature increase generally conclude that ozone-related mortality will increase with additional warming, with the risks higher at +2 K than at 1.5 K [27,28]. Of course, reductions in precursor emissions could reduce the future ozone concentrations, as well.

Nitrogen oxides (NO , NO_2) are produced by high temperature combustion processes and natural lightning, ground level appearance is a main contributor of the photochemical formation of ozone. The total nitrogen oxide emission has been significantly decreased in the last decade in developed countries; the emitted amount was reduced by approximately 30%. The nitrogen dioxide mixing ratio varies between 10 and 50 ppt at the sea level. The 150–250 ppb mixing ratio in urbanized areas can be the source of severe health problems (respiratory infections, asthma and sore throat) [29]. Atmospheric NO_2 is actively involved in radical and photochemical reactions; its amount significantly decreases by late midmorning.

Carbon-monoxide (CO) is not a key component in ozone formation in urban areas; however it has a significant part in the emission. The concentration of carbon-monoxide

of traffic weighted urban air can reach 100 ppm, while the background varies between 50 and 150 ppb. Carbon-dioxide (CO_2) is a key player in global warming; anthropogenic emissions are significant through combustion and traffic. The acidic property of the carbon-dioxide causes environmental damage through the dissolution in surface waters resulting in significant pH decrease, moreover it was pointed out that tropospheric warming has a stratospheric ozone depletion effect through cooling the stratosphere [30].

Methane (CH_4) is a powerful greenhouse component, its anthropogenic emission in urban areas is mainly associated with agricultural activity, decomposition of organic materials and other natural sources contribute to its formation [31]. It was pointed out, that methane contribution to enhance ozone level in photochemical smog is low, however through the slow build-up and break-down mechanisms contribute to the global tropospheric ozone formation.

Sulfur-dioxide (SO_2) is produced by coal feed power plants, combustion engines and volcanoes, biological decomposition of dimethyl-sulfide and hydrogen-sulfide form sulfur-dioxide as well. As a precursor of sulfuric acid, sulfur-dioxide influences global climate and the ozone layer [32], however anthropogenic production decreased because of the expansion of sulfur depleting industrial technologies.

Concerning high concentrations of particulate matter, it is established that frequency and duration of weather conditions similar in haze episodes may considerably increase compared to the actual climate projections [33]. During the night the thick pollution may even contribute to the UHI effect due to reduction of long-wave irradiation from the surfaces [34].

Effects of climate change on urban heat island

It is likely that a 1.5 K global temperature increase would affect the UHI phenomenon, as well. However, as the UHI effect is very complex and its behavior is strongly influenced by macroclimatic factors, it must be researched on multiple levels.

Considering direct connections between the UHI effect and the climate change the contemporary research publications are quite reticent, it is natural considering the different scales. Actual global climate model computations can have only ca. hundred kilometers of horizontal resolution. Though, the embedded regional climate models are of 10–25 km grid-point distance, this is still too coarse to correctly describe the spatial diversity of most urban areas. The chain of the various models and tools requested for direct modeling of climate change effects on UHI has been characterized [35]. A few studies apply fine resolution regional climate models to investigate the

UHI for selected cities. The unequivocal finding is that the UHI problem remains in any of the future warmer climates, but its intensity may mostly depend on increases of their population and city size [36,37].

Nevertheless, [38] deals with modeling of the behavior of cities considering the climate change. It is an accepted feature emphasizing the adaptability of the cities, other typical feature is to make several urban planning statements and these adaptation possibilities are planned mostly for climate extremes.

The results of weather conditions on UHI are a little bit ambiguous. As it was pointed out [39], the rate of the UHI increases only slightly with the increasing temperatures.

Heat stress (HS) was also investigated [40] and the obtained results strengthened previous data [39]: the UHI amplified just slightly, but HS increased remarkably both in urban and rural areas. It is important to note that both models used the RCP8.5 projection as basis.

Another research project [41] has used a modified scenario. In the first step a socio-economic model has been used to make assumptions about future building characteristics. Then, RCP-based climate projections have been applied for these hypothetical future urban areas. Importance of the urban structure has been emphasized, especially the compactness. This result also supports that urban expansion is a much greater contributing factor in the change of UHI than climate change, itself. It must be mentioned that similar results have been obtained considering heat-waves and OHI [42].

According to [43], a great threat is a kind of positive feedback: the higher the temperature is the more energy is used for air-conditioning, which causes greater Anthropogenic Heat Emission (AHE) that further increases urban air temperature.

On the other hand, we may also assume that a part of the large cities can develop efficient adaptation to mitigate deathful combination of heat-waves and UHI. According to [44] and [45] it may be useful. Urban morphology, water, and vegetation are factors affecting the differential warming between urban and rural areas. Increasing the surface albedo is another possible option.

According to the above results, the mean UHI values will not change remarkably with the global temperature rising, however the increasing number, length and intensity of heat waves will have a strong contribution by the increasing negative effects of UHI. Thus, the urban fabric will play an important role, but only in the periods of heat waves. The more compact is the city, the greater will be the negative effects (i.e. heat stress) for the inhabitants because the synergy of UHI and the heat wave phenomenon.

Effects of UAP and UHI on human health

Modern populations are more biologically sensitive to climate-related health risks than simpler communities were in the past, in certain aspects. The ageing population is more sensitive to heat-waves and weather extremities [46], but air pollution also poses serious health risks.

The two subsequent issues of climate change effects on human health were published by the Lancet Commission on Health and Climate Change. In the former one [47], there are 10 recommendations formulated for the next five years, mostly targeting the governments.

The last recommendation is to develop an independent Countdown to 2030 concerning Global Health and Climate Action to provide expertise in climate mitigation, to promote public health and to monitor the progress. Fulfillment of this recommendation is [48] planned to update every second year. The survey lists and documents all impacts of climate change on human health and establishes that the overwhelming majority of mortality and reduction of outdoor labor capacity occurred in low-income and medium-income countries, mostly un-insured.

The smallest size air pollution particles ($PM_{2.5}$) can be associated with severe health damage and increased mortality rate [49]. Furthermore, it was justified, that air pollution along with elevated temperatures favor health risk increase [50,51]. The allergic respiratory diseases have climate-sensitive components, so a rise in occurrence can be expected concerning asthma and rhinitis especially in urban environments [52]. Changes in projected PM-related mortality could increase or decrease, depending on the climate projections and emission assumptions [53,54].

Changes in common health effects caused by heat extremes and near-surface ozone concentrations are investigated [55]. Combination of a global climate model and an urban air chemistry model yielded the unequivocal consequence that the future summer mortality in South Korea is increased due to changes in both temperature and ozone, but the magnitude of ozone-related increase is much smaller than that of temperature-related increase.

The reactive oxygen (ROS) and nitrogen species (RNS) originating from air pollution have been investigated [56] and it was observed that ROS can increase oxidative stress through Fenton-like reactions, thus facilitating biological aging and cell death, moreover ROS and RNS derivatives can also play a significant role in immune responses.

The correlations between weather parameters and pollutants was examined [57] to find the climatic factors that have the most impact on the level of air pollution. High humidity decreases the air purification especially from gas components (CO_2 , NO_x and formaldehyde). The

strongest effects on gas components are rain and snow, which purify the air effectively.

The UHI effect and high pollution rates are the two most dangerous factors that simultaneously affect the urban population. The urban climate index [51] integrates health effect of high temperatures during heat-waves and high pollution concentrations. The risk values of air quality were also calculated so the health risk of both environmental hazards can be quantified [58].

In the case of heat waves, the high temperature of the daytime hours causes health problems, and symptoms of heat stress, heat stroke and dehydration occur more often in large cities regardless the climatic region. In this respect, [59] characterizes the heat waves in a new way. The studies [60] have shown that due to the aging population in the large cities in the southeast US the mortality rate of summer heat waves may be doubled over the next decades.

Studies on health impacts of global warming indicate significant increase of heat-waves in the cities, compared to their present frequency, but as [61] states, the strongest non-linear jump in the frequency of heat-waves occurs after 2 K warming.

The effects of climate change on health have been studied in four continents, in five Mediterranean cities [62^{••}]. It has been found that extreme high temperatures increase the levels of ozone and other air-pollutants which increase the number of cardiovascular and respiratory diseases, whereas water deficiency periods increase the occurrence of water-borne diseases.

Perspiration has an important cooling effect on human body, hence, if the wet-bulb temperature goes above 35 °C it may result in hyperthermia [63]. Also, besides high temperature, if the solar radiation is intense, dehydration can occur. Habitants of the coastal areas of the Red Sea and Arabian Sea are facing the high risk of heat stress and hyperthermia.

The increasing urban land surface temperature in the subtropical desert cities of the United States, such as in Phoenix, can increase the number of illnesses and risk factor [64]. Symptoms of heat related illnesses are mostly observed in correlation with daytime temperature, but no connection was found with the night time temperature.

The number of extreme heat events has been reported very high during the summer time in Bucharest [65]. Due to these events heat waves can appear and cause thermal risks in certain buildings of the city, the thermal risk is determined by standardized comfort indices. The city dwellers can prepare and protect themselves against the harmful effects of climate change with a well operating warning system.

There is correlation between low birth weight and temperature and precipitation [66[•]], found after examining data in 19 African countries. It was proved that the low born weight is prevalent mainly in sub-Saharan regions with the increase of hot days and decrease of precipitation. The results are independent of the household wealth indicator or place of living.

The effect of cold wave and heat wave on mortality rate in São Paulo, Brazil was searched [67], based on a linear model for 1996–2010. Cold weather had a stronger effect on mortality in this subtropical city with moderate climatic conditions, than hot weather. Heat waves mostly cause respiratory mortality, while cold waves are responsible for cardiovascular mortality. Women are more sensitive of heat-waves while men hardly tolerate cold periods.

Mental health is also affected by weather extremes and climate changes. There are two aspects of this impact as comprehended [68]. They are first, stress and mental health aspects due to experienced disasters, personally or even via the media, and second, special needs of people with mental illness who are at higher risk in case of extreme heat for their poor physical and mental health. The expected increases in extreme heat will increase the risk of disease and death for people of both groups. The situation might be even more dangerous for those taking prescription medications that impair the body's ability to regulate temperature.

Conclusion

In the previous sections of the review we examined the expected climate changes and the likely impacts of these changes on urban air pollution (UAP), urban heat island (UHI) and effects of both changes on human health. In conclusion, the followings can be established.

Even the modest, 1.5 K overall average global temperature increase in the near future can have significant influence on the chemical properties, concentrations and lifetime of pollution components. The high concentrations mostly occur in anticyclonic situations, characterized by thin mixed layer, when the pollution remains at near surface levels. In summer the anticyclones bring sunny weather supporting the ozone formation. Locally, higher surface temperatures in the polluted regions can trigger regional feedbacks in chemistry and local emissions that may increase peak levels of O₃ and PM_{2.5}.

The examination of the recent publications is not enough to conclude, whether UHI is stronger or weaker in case of the heat-waves, whereas the change should not be strong in case of 1.5 K global warming. The conclusions are quite diverse: on the one hand there seems to be a general accordance that the global warming does not change remarkably the UHI, itself. On the other hand, its occurrence and length seems to be increased due to the increasing

prevalence and duration of supporting macroclimatic situations. Circulation changes support UHI in more anticyclonic patterns, i.e. increase of sea-level pressure, and decrease it in more cyclonic patterns.

The emitted toxic components pose substantial health risk for human bio-systems. The main health risks due to air pollution are respiratory illness. In addition, the temperature change and climate change is going to have considerable effects on spreading of infectious diseases and formation of epidemics. The heat related mortality is higher in the city center compared to suburban areas. During heat waves, the death rates are much higher in large cities than in villages. There is growing evidence that the mental health impact from extreme events is substantial, often overshadowed by the physical health outcomes.

The 1.5 K global warming would cause substantial changes in UAP and UHI, consequently in their health effects, as well. However, the surveyed references are not enough to establish that in case of stronger warming these effects should be non-linearly higher than the ratio of the global mean temperature increases.

Conflicts of interest

None declared.

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Further reading

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